ART. XXII.—*Tertiary Geology of the Area between the Otiake River (Kurow District) and Duntroon, North Otago.*

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CONTENTS.

I. INTRODUCTION.

As will be seen from the accompanying geological map (fig. 1), the area described in this paper extends from the Otiake River, the southern boundary of the Kurow Survey District, to near Duntroon, on the Otago side of the Waitaki River. The district north-west of the Otiake River is dealt with in a later paper in this volume, but to save unnecessary repetition a full historical summary of the work of previous observers in that area, as well as in the present area, is given below.

In the geological map no attempt has been made to map the various types of gravels, as the delimitation of their boundary-lines and their differential characteristics will demand a great deal of detailed work. The gravel lands are now covered with vegetation and soil, and this fact renders their distinction difficult. The Wharekuri–Otekaike fault, which bounds the Kurow tilted block, follows an almost straight line, but between the Otekaike basin and the Otiake basin, a spur of the undermass, dipping easterly at 6° beneath the Tertiary rocks, apparently breaks the continuity of the main fault-line. It would appear that in this locality the low-lying block had failed to break away, as the stripped surface of the spur is certainly continuous with that of the uplifted block for some distance to the west of the main line of faulting. No convincing evidence was obtained to show whether the boundary scarps of this protruding spur were fault-scarps or fold-scarps, except in the neighbourhood of Newsome's Creek, where the quartz-grits were found lying directly on the sloping surface of the undermass on the southern side of the spur, three-quarters of a mile east of Trig. Station D. The surface and overlying quartz-grits at this point dip southerly at 30°, indicating that, in this locality at least, the scarp is a fold-surface.

McKay was the only geologist who investigated the area in any detail, and the sequence of rocks as recorded by him was characteristically accurate. His classification of the sediments was based almost entirely upon lithological characters, but he made large collections of fossils from several parts of the Waitaki Valley, and these were determined by the late Mr. Henry Suter two or three years ago, but the lists have not yet been published. McKay's account of the geology is rendered somewhat difficult

* Spelt also "Maerewhenua" and "Maraewhenua."

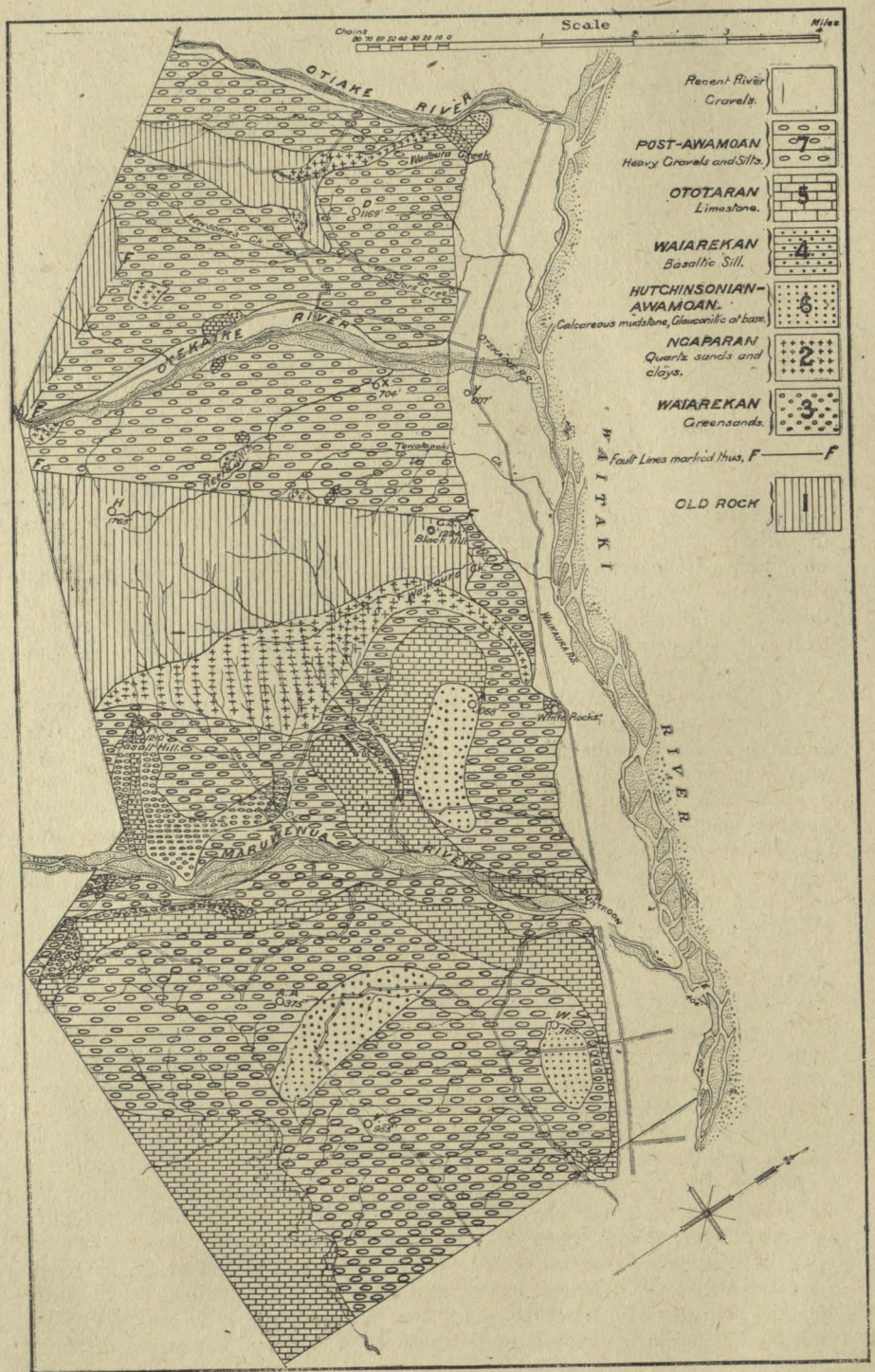

FIG. 1.—Geological map of the Waitaki Valley between the Otiake River and Duntroon. In the legend the order of superposition is indicated by the numbers.

to follow owing to the necessity he was under of finding in the series an unconformity marking the line of division between the Cretaceo-Tertiary and Tertiary systems of the old Geological Survey under Sir James Hector.

The relationship of the various rocks present in the area is obscured by the thick deposit of post-Tertiary gravels, and exposures are revealed only when the streams of the area have entrenched themselves in the gravels and cut through the Tertiary rocks. The outcrops of Tertiary rocks along the fault-lines have been mapped only where they were observed. They are probably continuous beneath the gravels.

The writer wishes to thank Mr. P. G. Morgan for kindly allowing him to examine the lists of fossils determined by the late Mr. Henry Suter from the collections made by McKay forty years ago. To Dr. J. Allan Thomson the writer is much indebted for assistance in determining the brachiopods, and for permission to incorporate his list of molluscan fossils from the upper beds at Otiake in the lists detailed below. Mr. H. Suter named many forms from the same beds for the writer some years ago, and his determinations are included in these lists.

The paper furnishes geological evidence for the existence of two strong faults, which are shown to be intimately connected with the great fault-system of Central Otago, so ably described by Cotton (1917A, p. 272). The elongated relatively depressed area of the Waitaki Valley, between the mountains of South Canterbury and North Otago, occupied by Tertiary beds, is shown to be a tectonic depression which is partly a graben and partly a fault-angle depression. McKay's statement that the Hutchinson Quarry beds lie above the Otekaike limestone is shown to be supported by the evidence. It is further shown that McKay's "two-limestone theory" is radically different from Park's "two-limestone theory," and that the latter's statement (1918, p. 110) that Hutton, Hector, and McKay considered the limestone of the Waitaki Valley to be of Hutchinsonian age is not warranted. On the evidence of the brachiopod fauna this limestone is shown to be Ototaran.

II. General Description of the Area.

Between the Otiake and the Otekaike Rivers, flowing in a north-easterly direction to join the Waitaki River, the surface rock is a thick deposit of coarse water-worn boulders and silt. The initial gravel tableland has been rather deeply trenched by the streams, and the Otiake and the Otekaike now flow in braided courses to join the trunk stream. Remnants of high-level terraces are to be seen near the school at Otekaike, indicating recent elevation. Before debouching from the mountains on to the gravel-covered plain these rivers flow in steep-sided gorges, and narrow terraces are noticeable on the sides of the streams. The mountainous country that flanks this part of the area on the south-west rises fairly rapidly to a height of over 6,000 ft. in the Kurow Mountains, or at least 5,000 ft. above the general level of the gravel tableland.

From Ben Lomond to Black Hill an even-topped gently sloping ridge extends almost to the main road, and the rise from the Otekaike basin to this ridge is abrupt. The quartz-grits that crop out in the basin of the Waikaura Creek have been deeply dissected and eroded, and in places the greywacke undermass crops to the surface, particularly in the higher country towards Ben Lomond. The country to the east is an elevated tableland, deeply dissected by the streams that traverse it. The surface rock is formed of heavy river-gravels and silts, and limestone is revealed

in many of the creeks, and forms prominent escarpments on the banks of many of the larger streams. The Maruwenua River, a north-easterly-flowing tributary of the Waitaki, rising in the neighbourhood of Dansey's Pass, where a distant sag is noticeable in the main Kakanui–Kurow Range, is flanked by the rather steeply sloping back of a tilted block, the stripped surface of which dips beneath the Tertiaries exposed in the neighbourhood of the river.

The Waitaki River flows in an east-south-east direction near the base of the well-preserved fault-scarp of the South Canterbury block mountains.

The Tertiary rocks in the Waitaki Valley occur in an elongated depression between the mountain-ranges of North Otago and South Canterbury, and the origin of this depression has been referred to various causes. Haast had no difficulty in imagining that a glacier was the agent of erosion; Hutton and Park invoked the aid of a pre-Tertiary river, the valley of which, after general subsidence of the land, was drowned by the encroachment of the sea, and the sedimentary deposits laid down. Marshall detected signs of tectonic movement in the neighbourhood of Wharekuri, and Cotton later elaborated the idea in his work on the block mountains of Otago, and described the depression as a somewhat complex graben between the uplifted block mountains of North Otago and Canterbury.

The Tertiary rocks consist of quartz conglomerates and sands, and sometimes fireclays, with seams of inferior brown coal. These rocks rest on the eroded surface of the older greywacke rock, and are followed by greensands, often pebbly, sandy, and micaceous, and containing marine fossils 20 ft. above the coal. These greensands pass up into more calcareous greensands, containing much less quartz and mica, but glauconitic casts of Foraminifera are abundant. The limestone which overlies these greensands sometimes has at its immediate base a band of calcareous greensand containing brachiopods in abundance; in other cases the transition from a calcareous glauconitic sand to a slightly glauconitic limestone is almost insensible. The glauconitic limestone passes up into a much harder limestone free from glauconite, and the latter rock is capped by very fossiliferous concretionary hardened bands, covered in turn by more sandy beds, which appear to be unfossiliferous in their upper part. Overlying these rocks unconformably is a heavy deposit of river-gravel and silts.

III. Historical Summary.

That the historical summary of the views of previous workers may be more easily followed, the classification as finally adopted by McKay for the Waitaki Valley is tabulated.

Age.	Formation.
Recent to Pleistocene	Alluvial and glacier deposits.
Lower Miocene	Pareora formation.
	(*a.*) Gravels and sands, with lignite-beds.
	(*b.*) Pareora clays.
Upper Eocene	(*a.*) Hutchinson Quarry beds.
	(*b.*) Otekaike limestone.
	(*c.*) *Kekenodon* beds (greensands).
Cretaceo-Tertiary	(*a.*) "Grey marls."
	(*b.*) Maruwenua limestone.
	(*c.*) Wharekuri greensands.
	(*d.*) Island sandstone.
	(*e.*) Coal-beds.

Hector, in 1865, classified the Waitaki arenaceous rocks as Lower Miocene, and the Oamaru rocks as Upper Miocene. In 1870 he considered the Oamaru rocks to be Older Tertiary, and those of the Waitaki Valley Middle Tertiary. In 1877 he placed the coal-grits, sandstones, and overlying limestones at Maruwenua in his Cretaceo-Tertiary system. In 1882 he considered the Otekaike limestone to be of Tertiary age, and at a higher horizon than the Maruwenua limestone (Cretaceo-Tertiary).

Hutton (1875, p. 46), after examining a collection of fossils from Otekaike, classed them as Upper Miocene (Pareoran or Awamoan); and (1875, p. 89) considered that the Tertiary rocks at Wharekuri occupied a depression "hollowed out by an Eocene glacier." The brown coal at Wharekuri was said to be Eocene. McKay (1877) reported on the geology of the Oamaru and Waitaki districts, and referred the Maruwenua limestone and the overlying fossiliferous horizon ("*Phorus* beds") to the Cretaceo-Tertiary system, and stated that the "equivalent beds of Hutchinson's Quarry, Oamaru, and even higher beds, assume the character of a calcareous sandstone at Otekaike, and at Big Gully (Wharekuri) of a tufaceous greensand." In the same report (1877, p. 58) he declared the impossibility of separating the Awamoan, either stratigraphically or otherwise, from the Hutchinsonian. In a later report (1882A) he described the Waitaki Valley more fully, and stated that the Tertiary rocks, comprising limestones and calcareous greensands of Upper Eocene age, rest indifferently on various members of the Cretaceo-Tertiary series. Certain sandstone gravels, often steeply tilted, were classed as Upper Pareoran (Awamoan), and the coal at Wharekuri was referred to this horizon. The Hutchinson Quarry beds at Wharekuri were said to rest conformably on the Otekaike limestone, which was classed as a Tertiary rock, quite distinct from the Maruwenua limestone of Cretaceo-Tertiary age. The "sandy beds with cement concretions" ("*Phorus* beds") above the limestone at Maruwenua were referred to the horizon of the "grey marls" of Cretaceo-Tertiary age, although the fossils "resemble those from Hutchinson's Quarry and the Otekaike limestone more than those of the 'grey marls.'" The Wharekuri greensands were said to be overlain unconformably by the "*Kekenodon* greensands" (a Tertiary rock), and to belong to the Cretaceo-Tertiary system. The fossiliferous beds that overlie the coal-rocks at Black Point were said to be at the same horizon as the island sandstone. The heavy angular gravels, containing boulders with Triassic and Permian fossils, were considered to be of glacial origin, the glaciers having taken their rise in the surrounding mountains. McKay collected fossils from Station Peak, opposite Otekaike, and stated that in the section exposed there "the Hutchinson's Quarry beds do not present their usual characters, and must be considered as merged in the Otekaike limestone." Again, referring to the same section, he affirmed that "the oldest beds seen are limestones as pure as, though less fossiliferous than, the higher part." In this locality and at Otekaike McKay considered that the limestone rests directly on the subschistose rocks.

In a later report (1882B) McKay still maintained that the coal-beds were of Pareora age, but that quartz sands and fireclays of Eocene age, similar to the rocks usually associated with the coal-seams, lay beneath the "*Kekenodon* greensands," of Eocene age. The Maruwenua limestone was now considered to consist of three distinct rocks. The upper part (the "*Phorus* beds," of Upper Cretaceo-Tertiary age of his former reports) was referred to the Hutchinson Quarry horizon, the middle part was

correlated with the Otekaike limestone, both being referred to the Tertiary; while the basal part of the Maruwenua limestone was stated to be of the same age as the Ototara limestone (Cretaceo-Tertiary). McKay asserted that, although these three rocks are quite conformable at Maruwenua, unconformity was deemed to be present, as the Otekaike limestone rested directly on the subschistose rocks at Otekaike and Station Peak. He gave a section (1882B, p. 104) showing the relationship between the two limestones, and the Hutchinson Quarry beds were shown above the limestone at Otekaike.

Hutton (1885, p. 547) described a section on the Rakaia River, Canterbury, at a locality called "The Curiosity Shop." The aim of the paper was to show that the division of the rocks in this locality into a Cretaceo-Tertiary and a Tertiary series was quite unjustifiable on either stratigraphical or palaeontological grounds. In the course of the paper he discussed the rocks and fossils of the Waitaki Valley, criticized adversely McKay's arguments in favour of an unconformity anywhere in the series, and showed clearly that the sequence at Wharekuri from the Hutchinson Quarry beds down to the greensands forms a single series. In a later paper (1887, p. 429) he again contended that the Otekaike limestone and the Maruwenua limestone belonged to the same series.

Park (1887, p. 139) traced the Ototaran stone almost continuously from Oamaru to Ngapara, where it rests conformably on greensands, the upper part of the greensands being represented at Oamaru by the Waiarekan tuffs. The limestone (at Ngapara) was said to have lost all the characteristics of the fine Oamaru building-stone, yet "standing on the high hills surrounding Ngapara it is quite obvious that the Ototara stone at one time formed a continuous bed" (*loc. cit.*, p. 140). Park (1904A, p. 416) determined the succession of the younger Tertiaries in South Canterbury and Otago to be, in descending order, (*a*) Oamaru stone, (*b*) marly and sandy clays, (*c*) marly greensands, often with calcareous concretions, (*d*) quartz-grits, fireclays, and coal; and he stated that "the sandy *Kekenodon* beds and underlying greensands, &c., form the base of the Tertiary beds in the old Waitaki Fiord, and, proceeding westward, they pass under a yellowish-brown limestone, which McKay calls the Otekaike limestone. I think there can be no doubt that this limestone is the horizontal equivalent of the Ngapara (Oamaru) limestone. But, without laying any stress upon the exact correlation of the limestones, we have in the Wharekuri basin a section of the Oamaru series exactly parallel with that at the Waihao River; and there is little to wonder at in this parallelism if these beds, as seems to me likely, were deposited on the floor of the same continuous sea. The position of the sandy beds [the greensands], containing, as we find, most, if not all, of the forms hitherto supposed to be typical of the Pareora [Awamoan] series, at once raises a question as to the relations of the Awamoa and other supposed Pareoras in North Otago to the Oamaru stone." In a note (1904, p. 418) Park stated that he had since obtained evidence in North Otago and South Canterbury which confirmed his conclusion that the Pareora beds (Awamoan) underlie the Oamaru (Waitaki) stone.

Hamilton (1904, p. 465) described some vertical faults striking north-north-west at Wharekuri, and his section showed the Wharekuri greensands in contact with the quartz-grits along a line of faulting. Park (1905) elaborated his position in regard to the position of the Pareora (Awamoan) fauna beneath the Waitaki stone, and contended that there were really

two limestone horizons in North Otago, separated by the Hutchinson Quarry and Awamoan beds The lower limestone he called the Oamaru stone, and the upper limestone the Waitaki stone, as it was strongly developed in the Waitaki Valley. The Maruwenua limestone and the Otekaike limestone at Wharekuri were considered to be at the same horizon above the Awamoan, which, it may be remarked, is an altogether different view from that which McKay held in regard to the relationship of the Ototara (Maruwenua) limestone and the Otekaike limestone. McKay certainly considered the two limestones distinct rocks; but the requirements of the Cretaceo-Tertiary theory demanded this, as a break had to occur somewhere in the series. Never did McKay dream of placing the Waitaki limestone above the Hutchinsonian and Awamoan horizons, for he always maintained the infra-position of the limestone in North Otago and South Canterbury (1882A, p. 65, and 1882B, p. 103). Park correlated the greensands at Wharekuri with the Hutchinson Quarry beds at Kakanui (1905, p. 523), but McKay had always maintained that the beds *above* the limestone in the Wharekuri area were undoubtedly the representatives of the Hutchinson Quarry beds at Oamaru. Park placed the coal-beds at Wharekuri at the base of the Tertiary series.

Marshall, Speight, and Cotton (1911, p. 405) stated that there was no evidence that the greensands lying beneath the Maruwenua limestone are the equvalent of the Hutchinson Quarry beds at Oamaru, but agreed with Park in his contention that the series is conformable.

Marshall (1915, p. 383) gave a list of fossils from the fossiliferous beds at Otiake, and referred them to the horizon of the Oamaru limestone (Ototaran).

Cotton (1917A, p. 285, and 1917B, p. 432) showed that the Waitaki River followed a complex graben along the northern boundary of the block-complex which forms the mountains of Otago, and he described several interesting examples of tectonic forms.

IV. Description of the Tertiary Beds.

(1.) *Trig. Station Z, Otiake River.*

The exposure of fossiliferous beds in this locality is seen on the face of a rather prominent cliff, near the Trig. Station Z, close to the Otiake River, and about a mile above the railway bridge. The beds dip 7° in a direction N. 20° W. The section exposed here is illustrated in fig. 2.

FIG. 2.—Section at Trig. Station Z, Otiake River. (*a*) Otekaike limestone; (*b*) glauconitic calcareous bands; (*c*) less glauconitic calcareous sandstones with glauconitic bands passing up into (*d*); (*d*) softer calcareous mudstone.

The lowest bed (*a*) is a compact light-yellowish-brown limestone (Otekaike limestone) containing abundant tests of Foraminifera, a small quantity of clear subangular minute grains of quartz, and some glauconitic casts of Foraminifera. Microscopic fossils are scattered through the mass of the rock. *Pachymagas huttoni* Thomson, *Pecten huttoni* (Park), *Limopsis aurita* (Brocchi), *Dentalium solidum* Hutt., *Cucullaea* sp. were found in the limestone. The overlying bed (*b*) is distinctly marked out from the underlying

limestone by its glauconitic nature and by the abundance of fossils it contains. Though occurring in (*c*) as well, the fossils are most abundant in the glauconitic bands. The bed (*b*) is hardened and concretionary, and is 3 ft. in thickness. Bed (*c*) is a calcareous, less glauconitic bed, showing a thickness of 20 ft., and containing occasional thin bands of glauconite with fossils. It appears to pass up into less fossiliferous, more sandy beds (*d*). The fossils collected from beds (*b*) and (*c*) are given below, and include the species collected by Dr. Thomson, Dr. Marshall, and the writer. The collector's name in each case is denoted by the initial letter of his name. For purposes of easy reference and comparison the list is arranged alphabetically. Recent species are marked with an asterisk.

Ampullina suturalis (Hutt.)	M, T, U.
Ancilla hebera (Hutt.)	M.
*—— *mucronata* (Sow.)	M, U.
*—— *novae-zelandiae* (Sow.)	M.
—— *papillata* (Tate)	T, U.
Anomia trigonopsis Hutt.	T.
Bathytoma sulcata excavata Sut.	M, T, U.
Borsonia rudis (Hutt.)	M, U.
**Calyptraea alta* (Hutt.)	T.
*—— *maculata* (Q. & G.)	M, T, U.
Cominella pulchra Sut.	M.
Corbula canaliculata Hutt.	M, T, U.
—— *humerosa* Hutt.	M, U.
—— *kaiparaensis* Sut.	M, U.
**Crassatellites obesus* (A. Ad.)	M, U.
Crepidula gregaria Sow.	M.
—— *striata* (Hutt.)	M, U.
Cucullaea attenuata Hutt.	M, U.
Cymatium minimum (Hutt.)	U.
Cymbiola corrugata (Hutt.)	M, T, U.
Cytherea chariessa Sut.	U.
*—— *oblongata* (Hanley)	M, T, U.
Dentalium mantelli Zitt.	M, U.
—— *pareorense* P. & S.	T.
—— *solidum* Hutt.	M, U.
**Divaricella cumingi* (Ad. & Ang.)	M, T, U.
**Dosinia greyi* Zitt.	M, T, U.
Drillia callimorpha Sut.	M.
Epitonium lyratum (Zitt.)	M, U.
Exilia dalli Sut.	M.
Ficus parvus Sut.	T.
**Fulgoraria gracilis* (Swains.)	M, T.
Leucosyrinx alta (Harris)	M, U.
—— *alta transenna* (Sut.)	M.
Lima colorata Hutt.	M, T.
**Limopsis aurita* (Brocchi)	M, T, U.
—— *catenata* Sut.	U.
**Loripes concinna* Hutt.	U.
Macrocallista assimilis (Hutt.)	M, U.

**Macrocallista multistriata* (Sow.)	M, T, U.
Mangilia blandiata Sut.	U.
Marginella harrisi Cossm.	M, U.
Mitra armorica Sut.	T, U.
Modiolaria elongata (Hutt.)	U.
**Modiolus australis* (Gray)	M.
**Murex zelandicus* Q. & G.	M, T, U.
**Natica zelandica* Q. & G.	M, T, U.
Nucula saggitata Sut.	U.
**Ostrea tatei* Sut.	T.
Pecten beethami Hutt.	T.
—— *chathamensis* Hutt.	T.
*—— *zelandiae* Gray	M.
Polinices gibbosus (Hutt.)	M, T, U.
—— *huttoni* Iher.	M, T, U.
**Psammobia lineolata* Gray	T.
Ptychatractus tenuiliratus Sut.	U.
Sinum cinctum (Hutt.)	M.
Siphonalia conoidea (Zitt.)	M.
*—— *nodosa* (Mart.)	M, T.
—— *turrita* Sut.	T, U.
**Struthiolaria vermis* (Mart.)	M.
**Tellina glabrella* Desh.	T.
Terebra orycta Sut.	M.
Teredo heaphyi Zitt.	M, T, U.
**Trichotropis clathrata* Sow.	M.
**Turbonilla zealandica* (Hutt.)	T.
Turris uttleyi Sut.	M, T, U.
Turritella ambulacrum Sow.	T.
*—— *carlottae* Wats.	M.
—— *cavershamensis* Harris	M, T, U.
—— *semiconcava* Sut.	M, T.
Typhis maccoyi T.-Woods	M, U.
**Venericardia difficilis* (Desh.)	M.
—— *pseutes* Sut.	T, U.
—— *purpurata* (Desh.)	T.
**Zenatia acinaces* (Q. & G.)	M.

Out of this list of seventy-six species twenty-six are Recent, giving a percentage of 34.

In addition to the molluscs, *Pachymagas huttoni* Thomson is abundant in the glauconitic bands. Two new species of *Surcula* were found in the writer's collection, and Dr. Thomson obtained a new species of *Vexillum.*

Every one of the above species occurs in the Awamoan beds elsewhere, and thirty-nine species have never been found below the "*Pachymagas parki*" greensand band (the upper limit of the Hutchinsonian) in the Oamaru district. Corals also occur in these beds. (NOTE.—To avoid circumlocution the writer will refer to these upper fossiliferous beds as the "Otiake beds.")

Dr. Marshall has published a list of fossils from this locality, and they are stated to have come from the limestone (1915, p. 383). All fossils

collected by the present writer have been gathered from the glauconitic band (*b*) and overlying bed, and at least 50 ft. of limestone is exposed below this bed. This limestone is poorly fossiliferous. Corals occur in the glauconitic bands above the limestone, as well as *Pachymagas huttoni* Thomson (possibly Marshall's *Magellania* sp.), but the writer did not find *Isis dactyla*. Nor was he more successful in finding a glauconitic band of greensand *below* the limestone in which the corals and brachiopods were said to occur.

Park (1918, p. 83, footnote) says, "Mr. Uttley states (*fide* Dr. J. A. Thomson) that the beds from which the collection was made lie above the Waitaki stone, and are undoubtedly Awamoan"; and on the next page of his report (1918, p. 84) he writes, "On the palaeontological evidence the so-called Waitaki stone at Otiake should be referred to the Awamoan instead of the Upper Hutchinsonian."

These statements, together with Marshall's view that the fossils came from the limestone, need some comment. The fossils were collected from the top of the section, with a considerable thickness of limestone below them. The fossils are almost certainly Awamoan, but the writer considers the limestone to be of Ototaran age. In the Waitaki Valley there is a lack of brachiopods that characterize the Hutchinsonian greensands of the Oamaru coastal district, particularly the brachiopod *Pachymagas parki* (Hutt.), which, though not restricted to the Hutchinsonian, occurs abundantly in a well-marked indurated glauconitic band, and marks the upper limit of the Hutchinsonian. In the absence of a brachiopod fauna it would scarcely be possible to differentiate this horizon, except perhaps lithologically, even in the Oamaru district, and the Hutchinsonian and Awamoan would, as far as the molluscan fauna is concerned, have to be considered as part and parcel of the same series. (See McKay, 1877, p. 58; Hutton, 1887, p. 416). The writer believes that this is the case in the Waitaki Valley, and that these fossiliferous beds at Otiake represent the Hutchinsonian and Awamoan horizons of the coastal district. McKay (1882A, p. 65) recognized the beds above the limestone at Wharekuri as Hutchinsonian, and these are at the same horizon as the Otiake beds. There is no evidence to show that the Otekaike limestone is other than Ototaran in age. The beds beneath the limestone are not seen, but on the right bank of the Otiake River, where the limestone again crops out, greyish-green foraminiferal sands, underlain by intensely dark greensands, crop out farther up the river, dipping in the same direction as the limestone; and a short distance from the outcrop of greensands the quartz-grits also dip in the same direction.

(2.) *Otekaike Special School.*

This is the locality (Geological Survey locality No. 481) where McKay collected fossils in 1881. His collection, he states, was made from the Otekaike limestone, which crops out on the left bank of the Otekaike River, two miles and half from the main road. Where exposed it contains a few fossils, *Cucullaea worthingtoni* Hutt. (?) and *Pachymagas huttoni* Thomson being the forms collected by the writer. McKay records ten forms, eight of which occur in the upper beds at Otiake. Traill's collection (Geol. Surv. loc. 259) is also said to have come from the limestone. Seven species were determined, and six occur in the upper beds at Otiake.

These geologists evidently failed to find a highly fossiliferous horizon in this locality. On the sloping right bank of the creek, immediately behind the school, the writer discovered, at the top of the limestone, two glauconitic beds crowded with fossils, which are undoubtedly at the same

horizon as the Otiake beds. Fully 40 ft. of limestone underlies, and its base is not seen. The fossils collected from the Otiake beds in this locality were—

Ampullina suturalis (Hutt.)
Ancilla papillata (Tate)
Anomia trigonopsis Hutt.
Bathytoma sulcata excavata Sut.
**Calyptraea alta* (Hutt.)
*—— *maculata* (Q. & G.)
Cominella pulchra (?) Sut.
Corbula canaliculata Hutt.
—— *humerosa* Hutt.
—— *kaiparaensis* Sut.
**Crassatellites obesus* (A. Ad.)
Crepidula gregaria Sow.
Cucullaea attenuata Hutt.
Cymbiola corrugata (Hutt.)
Cytherea chariessa Sut.
Dentalium pareorense P. & S.
—— *solidum* Hutt.
**Divaricella cumingi* (Ad. & Ang.)
Epitonium lyratum (Zitt.)
Leucosyrinx alta (Harris)
Lima colorata Hutt.
**Limopsis aurita* (Brocchi)
**Loripes concinna* Hutt.
Mangilia praecophinodes (?) Sut.
Marginella harrisi Cossm.
**Natica zelandica* Q. & G.
Nucula sagittata Sut.
Pecten chathamensis Hutt.
*—— *zelandiae* Gray
Polinices gibbosus (Hutt.)
—— *huttoni* Iher.
Siphonalia turrita Sut.
**Tellina glabrella* Desh.
Terebra orycta Sut.
Teredo heaphyi Zitt.
**Turbonilla zealandica* (Hutt.)
Turritella ambulacrum Sow.
—— *cavershamensis* Harris
—— *semiconcava* Sut.
Venericardia pseutes Sut.
*—— *purpurata* (Desh.)

Out of this list of forty-one species, two were doubtfully identified. Eleven species are Recent, giving a percentage of 27. This collection was obtained after two or three hours' work, and there is not the slightest doubt that many additional forms may be obtained from this locality.

The brachiopod *Pachymagas huttoni* Thomson is again very abundant, and corals are also found similar to those found at Trig. Station Z. McKay (1882A, p. 66) states that in this locality the Otekaike limestone rests directly on the Palaeozoic rocks, and he gives a section (1882B, p. 104) illustrating his views. It is true that a short distance from the present locality the old rock crops out, but McKay observed no junction, as the country between is obscured by heavy gravel deposits. The writer followed up the various small creeks that have cut deeply into the gravels, and found the quartz-grits dipping towards the limestone a short distance away close up to the mountain-front, so that there is no doubt that the limestone does not lie on the old rock at Otekaike. The section given by McKay (1882B, p. 104) was intended to illustrate his views of the relationship between the Otekaike limestone and the Maruwenua limestone, which he considered to belong to different systems. In his first report on the locality he gave a section (1882A, p. 75) showing the Otekaike limestone at a higher horizon than the Maruwenua limestone in its entirety; but in a later report during the same year he gave another section (1882B, p. 104), in which he modified his views considerably. He divided the Maruwenua limestone into three distinct rocks, and correlated the Otekaike limestone with the middle portion of the Maruwenua limestone, and the Hutchinson Quarry beds with the fossiliferous horizon ("*Phorus* beds") that lies at the top of the Maruwenua limestone. He had previously referred these fossiliferous beds to the top of the Cretaceo-Tertiary. His section shows clearly the Hutchinson Quarry beds lying above the Otekaike limestone at Otekaike (the present locality), although he makes no reference to them in his report. He frequently refers, however, to the Hutchinson Quarry beds

lying above the Otekaike limestone at Wharekuri. The writer has no doubt that if McKay had discovered the glauconitic fossiliferous beds above the limestone at Otekaike he would have referred them to the Hutchinson Quarry horizon, for his description of the latter beds at Wharekuri would apply equally well to the Otiake beds at Otiake and Otekaike. Although McKay made the break between the Cretaceo-Tertiary and Tertiary systems at the top of the lower third of the limestone at Maruwenua, yet he states that there is stratigraphical conformity throughout the section; but that unconformity is proved, as the Otekaike limestone rests on the old "subschistose" rocks at Otekaike. As there is no evidence forthcoming to show that this is so, and as the basal quartz-grits of the series are present, as shown above, unconformity has not been proved. McKay was perhaps justified on lithological grounds in dividing the limestone at Maruwenua into three portions. The "*Phorus* beds" at Maruwenua, as will be shown below, are similar to the Otiake beds, and therefore probably Hutchinsonian-Awamoan. The less glauconitic limestone below these at this locality has all the lithological characters of the limestone at Otekaike, while the more glauconitic basal portion of the limestone at Maruwenua represents the basal part of the Otekaike limestone, which is not visible in the present locality, as it is obscured by gravels.

The quartz-grits crop out again at the point where the Otekaike River leaves its gorge and debouches on to the gravel-covered plain. They lie near the foot of a steep escarpment of greywacke rock on the right bank of the stream, and mark the point of intersection of two strong faults, the one extending from Wharekuri to this point, and another trending in a north-easterly direction. The small exposure of the quartz-grits mentioned in the description of the beds at Otekaike lies on the line of the Wharekuri–Otekaike fault, and it will be shown in another paper in this volume that there are other outcrops of Tertiary rocks lying near the base of the mountain-front in the Kurow district. This fault has a north-westerly trend. The escarpment referred to above extends in a north-easterly direction towards the main road, and the crest of the evenly sloping ridge drops 500 ft. in a distance of three miles. Patches of quartz-grits and limestone crop out at various places at the foot of the scarp, and define the direction of this fault, which bounds the north-east portion of the great Kakanui tilted block (Cotton, 1917A, p. 279). The back slope of this portion of the block is stripped of its cover in the higher country towards Ben Lomond, but the covering strata (quartz-grits, greensands, limestone, &c.) are still preserved in the country extending north and south from Black Hill to Livingstone.

(3.) *White Rocks and Duntroon Area.*

In the Waikaura Creek, quartz-grits crop out to the east of Black Hill, and a prominent limestone mesa rises steeply from the bed of the creek. The slopes are buried in talus, and the intervening rocks are not exposed. The limestone resembles the Otekaike limestone in containing little glauconite. Its dip is westerly. From this point the Maruwenua tableland stretches to the south-east, covered by heavy gravels and silts, but the limestone is exposed in many places where the creeks have cut through the gravels.

At White Rocks, where the limestone crops out on the main road two miles above Duntroon, the highest rocks are the high-level river-gravels, overlying a limestone showing in places a thickness of 70 ft. The underlying rocks are not exposed, but the quartz-grits crop out about three-quarters of a miles up the valley, dipping in the same direction. The dip

of the limestone is easterly, at an angle of 6°. The lower part of the limestone is very glauconitic, and contains abundant Foraminifera and small echinoderms. Brachiopods also occur, being particularly abundant in one narrow band about 4 ft. wide. The limestone gradually gets less glauconitic and more indurated, and at the top it resembles the harder portions of the Otekaike limestone.

Pachymagas huttoni Thomson, *Epitonium lyratum* (Zitt.), *Graphularia* sp., and *Lima* sp. were found in this upper part.

The lower glauconitic limestone in its upper portion furnished the following fossils :—

Aetheia gaulteri (Morris)
Liothyrella landonensis Thomson
Neothyris tapirina (Hutt.)
Rhizothyris rhizoida (Hutt.)
Pachymagas huttoni Thomson
Pachymagas ellipticus Thomson
Terebratella totataensis (?) Thomson
Terebratulina suessi (Hutt.)
Epitonium lyratum (Zitt.)
Pecten huttoni (Park)

Foraminifera and echinoderms are plentiful in this bed.

In the neighbourhood of Duntroon, and in other places in the Maruwenua district, prominent salients in the shape of well-rounded hills and ridges are prominent above the surface of the tableland. They are capped with silts or gravels, and their flanks are usually covered with soil and grass, but where cuttings have been made through them fossiliferous beds are exposed which correspond with the horizon above the limestone (the Otiake beds). McKay clearly recognized that the form and position o these salients were an index of their nature, for, after describing them as capped with gravels, which are underlain by brown or light-coloured sands, in the lower part of which lenticular masses and beds of hard sandstone occur full of fossils, he says that " the fossiliferous beds underlying [the gravels] will probably be found in the isolated hills behind McMaster's Station " (1877, p. 57).

The Trig. Station A is situated on one of these prominent ridges, and on the road from Duntroon to the " Earthquake," which cuts through this ridge about one mile and a half from the railway-line, these upper fossiliferous beds crop out. In some places the fossils occurred in concretionary masses, but usually as casts. The looser portions of the rock are glauconitic and calcareous, but the fossils in these are very friable. From the hardened bed were obtained *Pachymagas huttoni* Thomson, and casts of *Turritella* sp., *Dentalium* sp., *Venericardia* sp. In the looser deposits lying immediately above, the following forms were obtained :—

Anomia trigonopsis Hutt. (?)
Cardium sp.
Corbula canaliculata Hutt.
**Crassatellites obesus* (A. Ad.)
Cytherea chariessa Sut.
**Limopsis aurita* (Brocchi)
Modiolus sp.
Venericardia pseutes Sut.

These beds are the " *Phorus* beds " of McKay, and this appears to be the locality from which he collected (Geol. Surv. loc. No. 178). These beds, as pointed out above, in his earlier reports he referred to the top of the Cretaceo-Tertiary, but subsequently he correlated them with the Hutchinson Quarry horizon, considering the underlying white limestone as the equivalent of the Otekaike limestone, while the basal portion of the limestone (usually very glauconitic) he referred to his Cretaceo-Tertiary system. The writer is in agreement with McKay in placing the " *Phorus* beds " in the Hutchinsonian, and believes they are the equivalent of the Otiake beds at Otekaike and Otiake.

At the " Earthquake " the limestone at the top of the cliffs is of the harder whitish variety, but lower down it gradually gets more glauconitic, and in the lower 10 ft. it contains an abundance of brachiopods.

The fossils collected from the lower part of the limestone were—

Aetheia gaulteri (Morris)
Liothyrella landonensis (?) Thomson
Neothyris tapirina (Hutt.)
Pachymagas ellipticus Thomson
Pachymagas huttoni Thomson
Rhizothyris rhizoida (Hutt.)
Terebratulina suessi (Hutt.)
Epitonium lyratum (Zitt.)

Foraminifera are also abundant.

Below this fossiliferous portion 2 ft. or 3 ft. of greyish-green glauconitic marly sands are exposed, and in the basin of Waipati Creek the quartz-grits are exposed dipping towards the limestone.

(4.) *Maruwenua River.*

The quartz-grits and overlying greensands can be seen at many places between Duntroon and Livingstone. At the latter place the grits are worked for gold, and are immediately overlain by a bed of fossiliferous greensand in which shark's teeth are abundant. This in turn is followed by concretionary greyish sands full of fossils (McKay, 1882B, p. 105). McKay, however, gave no list of fossils.

On the right bank of the Maruwenua River, at a point about a mile south-west of Trig. Station S (Maruwenua Survey District), a calcareous concretionary band full of fossils occurs in quartzose micaceous greensands, not far above the basal quartz sands. Twenty feet above this band occurs a sill of basalt, followed by another sill higher in the section, the two sills being separated by 20 ft. of greensands. The beds dip easterly at 10°. The calcareous concretionary band is full of fossils, but they are very difficult to extract. The late Mr. Henry Suter determined the following forms from a large quantity of material gathered by the writer. The work of identification was rendered difficult, as most of the fossils were casts.

**Ancilla novae-zelandiae* (Sow.)
**Capulus australis* (Lamk.)
Cardium waitakiense Sut.
Cardium n. sp.
Corbula humerosa Hutt.
Cylichnella enysi (Hutt.)
Mangilia n. sp.
**Nucula strangei* A. Ad.
**Polinices amphialus* (Wats.)
Sinum n. sp.
Surcula n. sp.
**Turritella carlottae* Wats.
**Venericardia difficilis* (Desh.)

Out of this small list four species are new. Mr. Suter has published the description of only one of these species—*Sinum fornicatum* Suter.

Some distance to the north-east a steep escarpment of the limestone occurs, the lower portion being glauconitic; the dip is easterly, at 7°. A few fossils were obtained from the lower part of the limestone :—

Aetheia gaulteri (Morris)
Epitonium lyratum (Zitt.)
Terebratulina suessi (Hutt.)

At four places in the road-cuttings in Blocks 2 and 3, Maruwenua Survey District, the writer found a hardened calcareous concretionary band lying above the limestone. The fossils were in the form of casts, but the position of the beds above the limestone indicates that the Otiake beds are widely spread throughout this part of the district.

(5.) *Station Peak.*

Although this locality is beyond the scope of the present paper, a brief reference should be made to it. On the Canterbury side of the Waitaki, opposite the mouth of the Otekaike River, there is an outcrop of fossiliferous Tertiary rocks lying near the base of a well-marked fault-scarp. The beds dip 40° to the west. This scarp, which bounds the

block mountains of South Canterbury, and close to the base of which the Waitaki River is now flowing, was diagnosed by Cotton on geomorphological evidence as a fault-scarp. The occurrence of these steeply dipping Tertiary beds at the base of the scarp confirms Cotton's view. This isolated patch of Tertiaries evidently rests on the toe of the splinter described by Cotton (1917B, p. 432). The surface of this splinter is a "fossil plain," and shows few signs of erosion. Although the Tertiary rocks that formerly covered it have been almost completely stripped, a small remnant has been preserved at Station Peak, close up to the fault-scarp at the back of the splinter. McKay collected fossils from these beds, and states that "in this section the Hutchinson's Quarry beds do not present their usual characters, and must be considered as merged in the Otekaike limestone" (1882A, p. 65). He further adds that "the lowest beds seen are limestones as pure as, though less fossiliferous than, the higher part. Upwards these beds pass into clay-marls resembling the fossiliferous Pareora beds." There is no doubt that McKay collected his fossils from the upper portions of the calcareous rocks at Station Peak, and that these fossiliferous rocks are underlain by a much less fossiliferous limestone. As has been shown above, the limestone at Otiake and Otekaike is also capped by a development of very fossiliferous beds, and it has been pointed out that these beds are probably widely extended beneath the gravel deposits of the Maruwenua tableland. McKay's collection from the beds at Station Peak were determined by the late Mr. Henry Suter. Of the thirty-one species specifically determined, nineteen occur in the Otiake beds at Otiake (Trig. Station Z). Of the remainder, ten species are common Awamoan fossils, *Lima lima* (L.) is Recent, and *Ancilla subgradata* (Tate) is apparently not found elsewhere. Further, ten of the species have never been found below the Hutchinsonian-Awamoan horizon of North Otago. These fossiliferous beds are almost certainly at the horizon of the Otiake beds (Hutchinsonian-Awamoan), lying above the main body of limestone of the Waitaki Valley.

V. Structure of the Area.

A fuller description of the structure will be given in a later paper after the area north-west of the Otiake River has been discussed. A fault (Wharekuri–Otekaike fault) is clearly defined by the outcrops of the basal quartz-grits, lying close to the base of the mountain-front, as shown on the map; whilst another fault, trending north-easterly, runs north-west of the conspicuous ridge extending from Black Hill as far as Ben Lomond. The geological evidence for the latter fault is clearly indicated by the outcrop of tilted quartz-grits and limestone at intervals at the foot of the scarp, and by the occurrence of the same beds on the back slope of the tilted block to the south-east. The majority of the streams draining this portion of the back slope flow in an easterly direction and are consequent on the deformation. These streams have stripped the Tertiary beds from the higher country in the vicinity of Ben Lomond, and the surface here exhibits the characteristic features of a tilted "fossil plain." Towards the Maruwenua River the plain disappears beneath the Tertiary basal grits and overlying beds in the basin of the stream. From Black Hill to Black Point the structure of the Tertiary Rocks is synclinal, indicating that the great Kakanui tilted block (Cotton, 1917A, p. 279) has in this locality been warped or folded. The Wharekuri–Otekaike fault forms the north-easterly boundary of the elevated block known as the Kurow Mountains. The south-easterly boundary of this block is a well-marked narrow

depression, which follows the line of the Black Hill–Ben Lomond fault as far as Dansey's Pass, near the watershed between the Kyeburn River and the Otiake and Maruwenua Rivers; but there are indications that this relatively depressed area beyond Ben Lomond is complex in structure, and not due to simple differential elevation along a single fault-line. Beyond the pass occurs the re-entrant forming the north-east corner of the great Maniototo depression (*loc. cit.*, p. 278). The Kurow block is bounded on the south-west by a conspicuous fault-scarp, which rises abruptly from the fault-angle of the Hawkdun tilted block (*loc. cit.*, p. 278).

From the description given it will be seen that the tilted block is bounded on the north-west by a tectonic depression, which in the lower course of the Otekaike River is a graben, and towards Dansey's Pass appears to be a narrow somewhat complex fault-angle or synclinal depression. This depression connects the Waitaki Valley tectonic depression with the Central Otago chain of tectonic depressions (*loc. cit.*, p. 268). The Kurow mountain-chain is an uplifted elongated block, bounded by faults on the north-east and south-west, and separated from the Kakanui block by a narrow probably complex tectonic depression. To the north-west the crest of the range is remarkably even when viewed from the Waitaki Valley, and it slopes gently towards the north-west. The Waitaki Valley, north-west of the Otekaike River, is a graben; south-east of this line the river flows for some distance in a fault-angle depression, the depression being bounded on the Canterbury side by the splintered fault-scarp of the South Canterbury block mountains.

VI. Conclusion.

The brachiopods listed above from the limestone at White Rocks all occur in the glauconitic base of the limestone at Maruwenua (Park, 1918, p. 83), with the exception of *Terebratella totaraensis* Thomson, which is doubtfully identified. *Murravia catinuliformis* (Tate) occurs in the limestone at the "Earthquake," in addition to the brachiopods collected by Park (*loc. cit.*) at Maruwenua. These brachiopods, with the exception *Pachymagas huttoni* Thomson, have not been found in rocks below the limestone in North Otago. Eight brachiopods—

Aetheia gaulteri (Morris)	*Pachymagas ellipticus* Thomson
Liothyrella landonensis Thomson	—— *huttoni* Thomson
Murravia catinuliformis (Tate)	*Rhizothyris rhizoida* (Hutt.)
Neothyris tapirina (Hutt.)	*Terebratulina suessi* (Hutt.)

can now be recorded from the body of the limestone in the Waitaki Valley. None of these fossils occurs in Park's so-called Upper Hutchinsonian of the Oamaru coastal district. None of them except *Rhizothyris rhizoida* (Hutt.) occurs in the "*Pachymagas parki*" band (Uttley, 1916, p. 20) of the coastal district, which Park would call Lower Hutchinsonian. The writer has found *Pachymagas parki* (Hutt.), *Aetheia gaulteri* (Morris), *Terebratulina suessi* (Hutt.), and *Rhizothyris rhizoida* (Hutt.) in the greensands between the nodular top of the limestone and the "*parki*" band. *Pachymagas ellipticus* Thomson, *Neothyris tapirina* (Hutt.), *Liothyrella landonensis* Thomson, and *Murravia catinuliformis* (Tate) have not been found by the writer above the limestone in the Landon Creek area. Of these, *Neothyris tapirina* (Hutt.) and *Liothyrella landonensis* Thomson are undoubted Ototaran fossils, and never occur above the Ototaran in the typical Oamaru district. The Hutchinsonian of the Oamaru district has as its highest member a hard glauconitic band crowded with *Pachymagas parki* (Hutt.), and usually accompanied with *Rhizothyris rhizoida* (Hutt.), which Park calls

Lower Hutchinsonian (1918, p. 109). He would, however, place the limestone in the present locality in the Upper Hutchinsonian; but the evidence is strongly against it, as the brachiopods mentioned above occur below the "*parki*" band in the Oamaru district. The Otiake beds, which lie above the limestone, contain an Awamoan molluscan fauna, and in the absence of the typical brachiopod of the Hutchinsonian, *Pachymagas parki* (Hutt.), it is a difficult matter to differentiate the Hutchinsonian horizon in the Waitaki Valley. McKay and Hutton both considered the Awamoa beds to be part and parcel of the same series, and this may be true when the molluscan fauna alone is taken into account, although the Awamoan beds are far more fossiliferous than the Hutchinsonian. The Otiake beds at their base are lithologically similar to the Hutchinson Quarry beds, and all the evidence available tends to show that the Otiake beds are the equivalent of the Hutchinsonian-Awamoan horizon of the typical Oamaru district. The Otekaike limestone has been shown to be underlain by the basal rocks of the Tertiary series, and not by the "subschistose" rocks of McKay, and this fact invalidates the only evidence produced by McKay to prove an unconformity between the lower part of the Maruwenua limestone and the middle portion of that rock (his Otekaike limestone). It has been shown that McKay considered the Hutchinsonian ("*Phorus* beds") to lie above the limestone, and not below it as Park believes. The Waitaki Valley in the present locality is a tectonic depression, being partly a graben and partly a fault-angle depression. Extensive faulting has been proved by geological evidence.

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